THE 2 MS CHANDRA DEEP FIELD-NORTH

Moderate-luminosity AGNs and dusty starburst galaxies

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Abstract The 2 Ms Chandra Deep Field-North survey provides the deepest view of the Universe in the 0.5–8.0 keV X-ray band. In this brief review we investigate the diversity of X-ray selected sources and focus on the constraints placed on AGNs (including binary AGNs) in high-redshift submm galaxies.

Keywords: surveys — cosmology — X-rays: active galaxies — X-rays: galaxies

1. Introduction

The 2 Ms Chandra Deep Field-North (CDF-N) survey provides the deepest view of the Universe in the 0.5–8.0 keV band. It is ≈ 2 times deeper than the 1 Ms *Chandra* surveys (Brandt et al. 2001; Giacconi et al. 2002) and ≈ 2 orders of magnitude more sensitive than pre-*Chandra* surveys. Five hundred and three (503) highly significant sources are detected over the 448 arcmin^2 area of the CDF-N, including 20 sources in the central 5.3 arcmin^2 Hubble Deep Field-North region (Alexander et al. 2003a; see Fig 1). The on-axis flux limits of $\approx 2.3 \times 10^{-17}$ erg cm^{-2} s^{-1} (0.5–2.0 keV) and $\approx 1.4 \times 10^{-16}$ erg cm^{-2} s^{-1} (2–8 keV) are sensitive enough to detect moderate-luminosity starburst galaxies out to $z \approx 1$ and moderate-luminosity AGNs out to $z \approx 10$.

In addition to deep X-ray observations, the CDF-N region also has deep multi-wavelength imaging (radio, submm, infrared, and optical) and deep optical spectroscopy (e.g., Barger et al. 2003a). Most recently, the CDF-N has been observed with the ACS camera on *HST* and will be observed with the IRAC and MIPS cameras on *SIRTF* as part of the GOODS project (Dickinson & Giavalisco 2003). The *HST* data, in particular, are providing key morphological and environmental constraints on the X-ray detected sources.

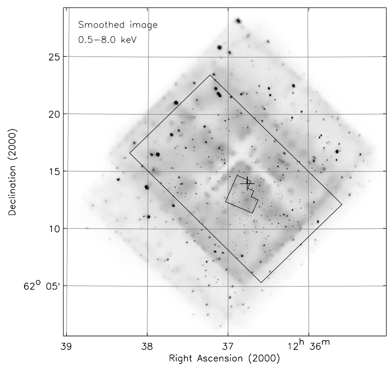

Figure 1. Adaptively smoothed (2.5σ) 0.5–8.0 keV image of the CDF-N (see Fig 3 of Alexander et al. 2003a).

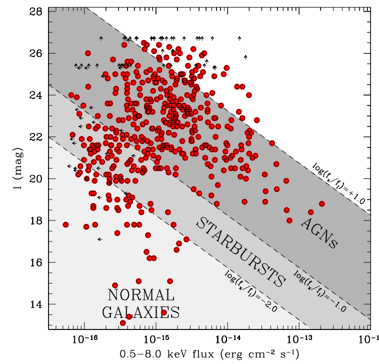

Figure 2. I-band magnitude versus X-ray flux. The shaded regions show approximate flux ratios for different source types.

2. The diversity of X-ray selected sources

The X-ray-to-optical flux ratios of the faintest X-ray sources span up to five orders of magnitude, indicating a broad variety of source types (including AGNs and starburst galaxies; see Fig 2). Many of the AGNs show the optical characteristics of AGN activity (e.g., broad or highly ionised emission lines). However, a large fraction (perhaps $> 50\%$) are either too faint for optical spectroscopic identification or do not show typical AGN optical features (e.g., Alexander et al. 2001; Hornschemeier et al. 2001; Comastri et al. 2003). It is the X-ray properties of these sources that identify them as AGNs [e.g., luminous, and often variable and/or hard (i.e., $\Gamma < 1$) X-ray emission]. The corresponding AGN source density ($\approx$ 6000 deg^{-2}) is $\approx$ 10 times higher than that found by the deepest optical surveys (e.g., Wolf et al. 2003).

X-ray spectral analyses of the X-ray brightest AGNs indicate that both obscured and unobscured sources are found (Vignali et al. 2002; Bauer et al. 2003). However, few Compton-thick sources have been identified, and current analyses suggest that they are rare even at faint X-ray fluxes (e.g., Alexander et al. 2003a). Whilst AGNs are identified out to $z = 5.189$ fewer high-redshift moderate-luminosity AGNs are found than many models predict (e.g., Barger et al. 2003b). Indeed, current analyses suggest that moderate-luminosity AGN activity peaked at comparitively low redshifts (e.g., Cowie et al. 2003).

A large number of apparently normal galaxies are detected at faint X-ray fluxes (e.g., Hornschemeier et al. 2001). The properties of these sources at infrared, radio, X-ray, and optical wavelengths are consistent with those expected from starburst and normal galaxies (e.g., Alexander et al. 2002; Bauer et al. 2002; Hornschemeier et al. 2003). Furthermore, their X-ray and radio

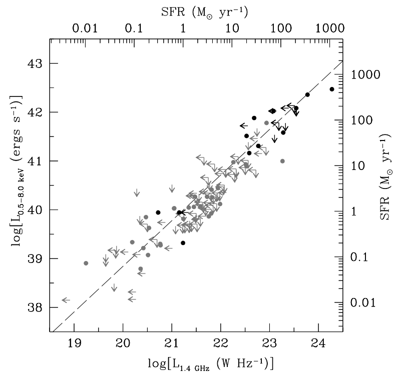

Figure 3. X-ray-radio luminosity comparison for CDF-N (black) and local (grey) sources (see Fig 4 in Bauer et al. 2002).

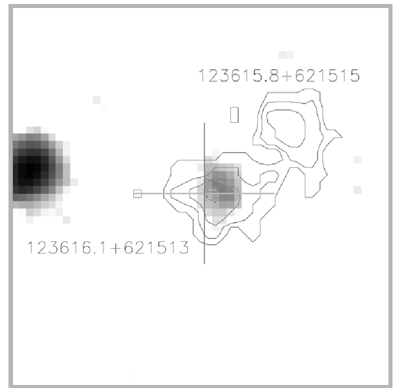

Figure 4. Submm source (I-band image; X-ray contours) with likely binary AGNs (see Fig 2 in Alexander et al. 2003b).

luminosities are correlated in the same manner as for local starburst galaxies, suggesting that the X-ray emission can be used directly as a star-formation indicator (Bauer et al. 2002; Ranalli et al. 2003; see Fig 3). While the X-ray emission from the low-redshift, low-luminosity sources could be produced by a single ultra-luminous X-ray source (e.g., Hornschemeier et al. 2003), the majority of these sources have X-ray luminosities between those of M 82 and NGC 3256, implying moderate-to-luminous star-formation activity.

3. AGNs in high-redshift submm galaxies

Deep submm surveys have uncovered a population of dust-enshrouded, luminous galaxies at high-redshift ($z \approx$ 1–4; e.g., Smail et al. 1997; Hughes et al. 1998). Both AGN and starburst activity can theoretically account for the large luminosities of these sources; however, since few (< 10%) submm sources have X-ray counterparts in moderately deep X-ray surveys, AGNs can only be bolometrically important if they are Compton thick (e.g., Fabian et al. 2000; Hornschemeier et al. 2000). The CDF-N is sensitive enough to place direct constraints on the presence and properties of AGNs in submm galaxies.

Seven bright ($f_{850\mu\rm m} \geq$ 5 mJy; S/N≥ 4) submm sources have X-ray counterparts in a 70.3 arcmin^2 area centred on the CDF-N (Alexander et al. 2003b); using the most recent submm catalog of Borys et al. (2003), this corresponds to 54% of the bright submm sources! The X-ray emission from five of these sources is clearly AGN dominated, while the X-ray emission from the other two sources may be star-formation dominated (Alexander et al. 2003b). X-ray spectral analyses of the five AGNs indicate that all are heavily obscured; however, with 1–2 possible exceptions, the absorption appears to be Compton thin

and the AGNs are of moderate luminosity (Alexander et al. 2003b). Consequently, the AGNs make a negligible contribution to the bolometric luminosity. This may imply that the central massive black holes are in their growth phase.

Interestingly, two ($\approx$ 30%) of the seven submm sources are individually associated with X-ray pairs (Alexander et al. 2003b; see Fig 4). The small angular separations of these pairs ($\approx$ 2–3$''$) correspond to just $\approx$ 20 kpc at $z = 2$ (approximately one galactic diameter); the probability of a chance association is $<$1%. We may be witnessing the interaction or merging of AGNs in these sources (a low-redshift example of this binary AGN behaviour is NGC 6240; Komossa et al. 2003). Since only five ($\approx$ 3%) of the 193 X-ray sources in this region are close X-ray pairs ($<$3$''$ separation), binary AGN behaviour appears to be closely associated with submm galaxies (see also Smail et al. 2003).

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